c Solutions of aluminum sulfate and sodium hydroxide are mixed.
d Solutions of calcium bromide and sodium phosphate are mixed.

4.40 For each of the following, write molecular and net ionic equations for any precipitation reaction that occurs. If no reaction occurs, indicate this.
a Zinc chloride and sodium sulfide are dissolved in water.
b Sodium sulfide and calcium chloride are dissolved in water.
c Magnesium sulfate and potassium bromide are dissolved in water.
d Magnesium sulfate and potassium carbonate are dissolved in water.

Strong and Weak Acids and Bases

4.41 Classify each of the following as a strong or weak acid or base.
a NH_3 b HCNO c $Mg(OH)_2$ d $HClO_3$

4.42 Classify each of the following as a strong or weak acid or base.
a HF b KOH c $HClO_4$ d HIO

Neutralization Reactions

4.43 Complete and balance each of the following molecular equations (in aqueous solution); include phase labels. Then, for each, write the net ionic equation.
a $NaOH + HNO_3 \longrightarrow$
b $HCl + Ba(OH)_2 \longrightarrow$
c $HC_2H_3O_2 + Ca(OH)_2 \longrightarrow$
d $NH_3 + HNO_3 \longrightarrow$

4.44 Complete and balance each of the following molecular equations (in aqueous solution); include phase labels. Then, for each, write the net ionic equation.
a $Ba(OH)_2 + HC_2H_3O_2 \longrightarrow$
b $H_2SO_4 + KOH \longrightarrow$
c $Al(OH)_3 + HCl \longrightarrow$
d $HClO + Sr(OH)_2 \longrightarrow$

4.45 For each of the following, write the molecular equation, including phase labels. Then write the net ionic equation. Note that the salts formed in these reactions are soluble.
a the neutralization of hydrobromic acid with calcium hydroxide solution
b the reaction of solid aluminum hydroxide with nitric acid
c the reaction of aqueous hydrogen cyanide with calcium hydroxide solution
d the neutralization of lithium hydroxide solution by aqueous hydrogen cyanide

4.46 For each of the following, write the molecular equation, including phase labels. Then write the net ionic equation. Note that the salts formed in these reactions are soluble.
a the neutralization of lithium hydroxide solution by aqueous chloric acid
b the reaction of barium hydroxide solution and aqueous nitrous acid
c the reaction of sodium hydroxide solution and aqueous nitrous acid
d the neutralization of aqueous hydrogen cyanide by aqueous strontium hydroxide

4.47 Complete the right side of each of the following molecular equations. Then write the net ionic equations. Assume all salts formed are soluble. Acid salts are possible.
a $Ca(OH)_2(aq) + 2H_2SO_4(aq) \longrightarrow$
b $2H_3PO_4(aq) + Ca(OH)_2(aq) \longrightarrow$
c $NaOH(aq) + H_2SO_4(aq) \longrightarrow$
d $Sr(OH)_2(aq) + 2H_2CO_3(aq) \longrightarrow$

4.48 Complete the right side of each of the following molecular equations. Then write the net ionic equations. Assume all salts formed are soluble. Acid salts are possible.
a $2KOH(aq) + H_3PO_4(aq) \longrightarrow$
b $3H_2SO_4(aq) + 2Al(OH)_3(s) \longrightarrow$
c $2HC_2H_3O_2(aq) + Ca(OH)_2(aq) \longrightarrow$
d $H_2SO_3(aq) + NaOH(aq) \longrightarrow$

4.49 Write molecular and net ionic equations for the successive neutralizations of each acidic hydrogen of sulfurous acid by aqueous calcium hydroxide. $CaSO_3$ is insoluble; the acid salt is soluble.

4.50 Write molecular and net ionic equations for the successive neutralizations of each acidic hydrogen of phosphoric acid by calcium hydroxide solution. $Ca_3(PO_4)_2$ is insoluble; assume that the acid salts are soluble.

Reactions Evolving a Gas

4.51 The following reactions occur in aqueous solution. Complete and balance the molecular equations using phase labels. Then write the net ionic equations.
a $BaCO_3 + HNO_3 \longrightarrow$
b $K_2S + HCl \longrightarrow$
c $CaSO_3(s) + HI \longrightarrow$

4.52 The following reactions occur in aqueous solution. Complete and balance the molecular equations using phase labels. Then write the net ionic equations.
a $CaS + HBr \longrightarrow$ b $MgCO_3 + HNO_3 \longrightarrow$
c $K_2SO_3 + H_2SO_4 \longrightarrow$

4.53 Write the molecular equation and the net ionic equation for the reaction of solid iron(II) sulfide and hydrochloric acid. Add phase labels.

4.54 Write the molecular equation and the net ionic equation for the reaction of solid barium carbonate and hydrogen bromide in aqueous solution. Add phase labels.

Oxidation Numbers

4.55 Obtain the oxidation number for the element noted in each of the following.
a Mn in K_2MnO_4 b Br in $KBrO_4$
c Nb in NbO_2 d Ga in Ga_2O_3

4.56 Obtain the oxidation number for the element noted in each of the following.
a Cr in CrO_3 b Hg in Hg_2Cl_2
c Ga in $Ga(OH)_3$ d P in Na_3PO_4

4.84 A soluble iodide was dissolved in water. Then an excess of silver nitrate, $AgNO_3$, was added to precipitate all of the iodide ion as silver iodide, AgI. If 1.545 g of the soluble iodide gave 2.185 g of silver iodide, how many grams of iodine are in the sample of soluble iodide? What is the mass percentage of iodine, I, in the compound?

4.85 Gold has compounds containing gold(I) ion or gold(III) ion. A compound of gold and chlorine was treated with a solution of silver nitrate, $AgNO_3$, to convert the chloride ion in the compound to a precipitate of AgCl. A 162.7-mg sample of the gold compound gave 100.3 mg AgCl.

a Calculate the percentage of the chlorine in the gold compound.

b Decide whether the formula of the compound is AuCl or $AuCl_3$.

4.86 Copper has compounds with copper(I) ion or copper(II) ion. A compound of copper and chlorine was treated with a solution of silver nitrate, $AgNO_3$, to convert the chloride ion in the compound to a precipitate of AgCl. A 59.40-mg sample of the copper compound gave 86.00 mg AgCl.

a Calculate the percentage of chlorine in the copper compound.

b Decide whether the formula of the compound is CuCl or $CuCl_2$.

4.87 A compound of iron and chlorine is soluble in water. An excess of silver nitrate was added to precipitate the chloride ion as silver chloride. If a 134.8-mg sample of the compound gave 304.8 mg AgCl, what is the formula of the compound?

4.88 A 1.345-g sample of a compound of barium and oxygen was dissolved in hydrochloric acid to give a solution of barium ion, which was then precipitated with an excess of potassium chromate to give 2.012 g of barium chromate, $BaCrO_4$. What is the formula of the compound?

Volumetric Analysis

4.89 A flask contains 49.8 mL of 0.150 *M* $Ca(OH)_2$ (calcium hydroxide). How many milliliters of 0.500 *M* Na_2CO_3 (sodium carbonate) are required to react completely with the calcium hydroxide in the following reaction?

$$Na_2CO_3(aq) + Ca(OH)_2(aq) \longrightarrow CaCO_3(s) + 2NaOH(aq)$$

4.90 What volume of 0.250 *M* HNO_3 (nitric acid) reacts with 44.8 mL of 0.150 *M* Na_2CO_3 (sodium carbonate) in the following reaction?

$$2HNO_3(aq) + Na_2CO_3(aq) \longrightarrow 2NaNO_3(aq) + H_2O(l) + CO_2(g)$$

4.91 How many milliliters of 0.150 *M* H_2SO_4 (sulfuric acid) are required to react with 8.20 g of sodium hydrogen carbonate, $NaHCO_3$, according to the following equation?

$$H_2SO_4(aq) + 2NaHCO_3(aq) \longrightarrow Na_2SO_4(aq) + 2H_2O(l) + 2CO_2(g)$$

4.92 How many milliliters of 0.250 *M* $KMnO_4$ are needed to react with 3.55 g of iron(II) sulfate, $FeSO_4$? The reaction is as follows:

$$10FeSO_4(aq) + 2KMnO_4(aq) + 8H_2SO_4(aq) \longrightarrow 5Fe_2(SO_4)_3(aq) + 2MnSO_4(aq) + K_2SO_4(aq) + 8H_2O(l)$$

4.93 A 3.75-g sample of iron ore is transformed to a solution of iron(II) sulfate, $FeSO_4$, and this solution is titrated with 0.150 *M* $K_2Cr_2O_7$ (potassium dichromate). If it requires 43.7 mL of potassium dichromate solution to titrate the iron(II) sulfate solution, what is the percentage of iron in the ore? The reaction is

$$6FeSO_4(aq) + K_2Cr_2O_7(aq) + 7H_2SO_4(aq) \longrightarrow 3Fe_2(SO_4)_3(aq) + Cr_2(SO_4)_3(aq) + 7H_2O(l) + K_2SO_4(aq)$$

4.94 A solution of hydrogen peroxide, H_2O_2, is titrated with a solution of potassium permanganate, $KMnO_4$. The reaction is

$$5H_2O_2(aq) + 2KMnO_4(aq) + 3H_2SO_4(aq) \longrightarrow 5O_2(g) + 2MnSO_4(aq) + K_2SO_4(aq) + 8H_2O(l)$$

It requires 51.7 mL of 0.145 *M* $KMnO_4$ to titrate 20.0 g of the solution of hydrogen peroxide. What is the mass percentage of H_2O_2 in the solution?

General Problems

Key: These problems provide more practice but are not divided by topic or keyed to exercises. Each section ends with essay questions. Odd-numbered problems and the even-numbered problems that follow are similar; answers to all odd-numbered problems except the essay questions are given in the back of the book.

4.95 Aluminum metal reacts with perchloric acid to produce hydrogen gas and a solution of aluminum perchlorate. Write the molecular equation for this reaction. Then write the corresponding net ionic equation.

4.96 Magnesium metal reacts with hydrobromic acid to produce hydrogen gas and a solution of magnesium bromide. Write the molecular equation for this reaction. Then write the corresponding net ionic equation.

4.97 Potassium sulfate solution reacts with barium bromide solution to produce a precipitate of barium sulfate and a solution of potassium bromide. Write the molecular equation for this reaction. Then write the corresponding net ionic equation.

4.98 Nickel(II) sulfate solution reacts with sodium hydroxide solution to produce a precipitate of nickel(II)

4.57 Obtain the oxidation number for the element noted in each of the following.

a N in NH_2^- b I in IO_3^-
c H in H_2 d Cl in $HClO_4$

4.58 Obtain the oxidation number for the element noted in each of the following.

a N in N_2 b Cr in CrO_4^{2-}
c Zn in $Zn(OH)_4^{2-}$ d As in $H_2AsO_3^-$

4.59 Determine the oxidation numbers of all the elements in each of the following compounds. (*Hint:* Look at the ions present.)

a $Hg_2(ClO_4)_2$ b $Cr_2(SO_4)_3$
c $CoSeO_4$ d $Pb(OH)_2$

4.60 Determine the oxidation numbers of all the elements in each of the following compounds. (*Hint:* Look at the ions present.)

a $Mn(ClO_2)_2$ b $Fe_2(CrO_4)_3$
c $HgCr_2O_7$ d $Co_3(PO_4)_2$

Describing Oxidation–Reduction Reactions

4.61 In the following reactions, label the oxidizing agent and the reducing agent.

a $Co(s) + Cl_2(g) \longrightarrow CoCl_2(s)$
b $P_4(s) + 5O_2(g) \longrightarrow P_4O_{10}(s)$

4.62 In the following reactions, label the oxidizing agent and the reducing agent.

a $ZnO(s) + C(s) \longrightarrow Zn(g) + CO(g)$
b $8Fe(s) + S_8(s) \longrightarrow 8FeS(s)$

4.63 In the following reactions, label the oxidizing agent and the reducing agent.

a $2Al(s) + 3F_2(g) \longrightarrow 2AlF_3(s)$
b $Hg^{2+}(aq) + NO_2^-(aq) + H_2O(l) \longrightarrow Hg(s) + 2H^+(aq) + NO_3^-(aq)$

4.64 In the following reactions, label the oxidizing agent and the reducing agent.

a $PbS(s) + 4H_2O_2(aq) \longrightarrow PbSO_4(s) + 4H_2O(l)$
b $Fe_2O_3(s) + 3CO(g) \longrightarrow 2Fe(s) + 3CO_2(g)$

Balancing Oxidation–Reduction Reactions

4.65 Balance the following oxidation–reduction reactions by the half-reaction method.

a $CuCl_2(aq) + Al(s) \longrightarrow AlCl_3(aq) + Cu(s)$
b $Cr^{3+}(aq) + Zn(s) \longrightarrow Cr(s) + Zn^{2+}(aq)$

4.66 Balance the following oxidation–reduction reactions by the half-reaction method.

a $FeI_3(aq) + Mg(s) \longrightarrow Fe(s) + MgI_2(aq)$
b $H_2(g) + Ag^+(aq) \longrightarrow Ag(s) + H^+(aq)$

Molarity

4.67 A sample of 0.0512 mol of iron(III) chloride, $FeCl_3$, was dissolved in water to give 50.0 mL of solution. What is the molarity of the solution?

4.68 A 50.0-mL volume of $AgNO_3$ solution contains 0.0345 mol $AgNO_3$ (silver nitrate). What is the molarity of the solution?

4.69 An aqueous solution is made from 0.798 g of potassium permanganate, $KMnO_4$. If the volume of solution is 50.0 mL, what is the molarity of $KMnO_4$ in the solution?

4.70 A sample of oxalic acid, $H_2C_2O_4$, weighing 1.200 g is placed in a 100.0-mL volumetric flask, which is then filled to the mark with water. What is the molarity of the solution?

4.71 What volume of 0.120 *M* $CuSO_4$ is required to give 0.250 mol of copper(II) sulfate, $CuSO_4$?

4.72 How many milliliters of 0.126 *M* $HClO_4$ (perchloric acid) are required to give 0.150 mol $HClO_4$?

4.73 An experiment calls for 0.0353 g of potassium hydroxide, KOH. How many milliliters of 0.0176 *M* KOH are required?

4.74 What is the volume (in milliliters) of 0.100 *M* H_2SO_4 (sulfuric acid) containing 0.949 g H_2SO_4?

4.75 Heme, obtained from red blood cells, binds oxygen, O_2. How many moles of heme are there in 150 mL of 0.0019 *M* heme solution?

4.76 Insulin is a hormone that controls the use of glucose in the body. How many moles of insulin are required to make up 28 mL of 0.0048 *M* insulin solution?

4.77 Describe how you would prepare 2.50×10^2 mL of 0.50 *M* Na_2SO_4. What mass (in grams) of sodium sulfate, Na_2SO_4, is needed?

4.78 How many grams of sodium dichromate, $Na_2Cr_2O_7$, should be added to a 100.0-mL volumetric flask to prepare 0.025 *M* $Na_2Cr_2O_7$ when the flask is filled to the mark with water?

4.79 You wish to prepare 0.12 *M* HNO_3 from a stock solution of nitric acid that is 15.8 *M*. How many milliliters of the stock solution do you require to make up 1.00 L of 0.12 *M* HNO_3?

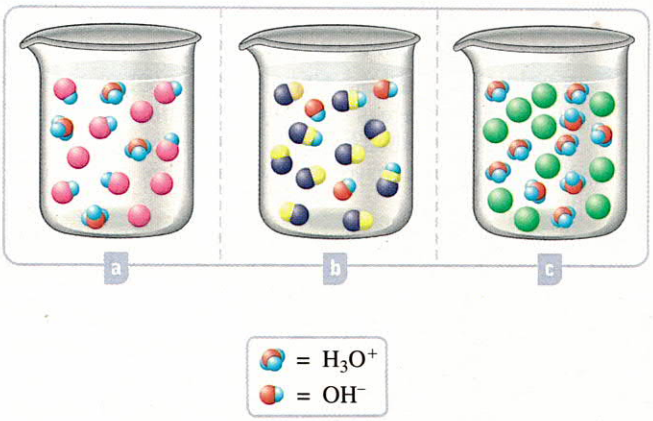
4.80 A chemist wants to prepare 0.75 *M* HCl. Commercial hydrochloric acid is 12.4 *M*. How many milliliters of the commercial acid does the chemist require to make up 1.50 L of the dilute acid?

4.81 Calculate the concentrations of each ion present in a solution that results from mixing 50.0 mL of a 0.20 *M* $NaClO_3(aq)$ solution with 25.0 mL of a 0.20 *M* $Na_2SO_4(aq)$ solution. Assume that the volumes are additive.

4.82 A 4.00 g sample of KCl is dissolved in 10.0 mL of water. The resulting solution is then added to 60.0 mL of a 0.500 *M* $CaCl_2(aq)$ solution. Assuming that the volumes are additive, calculate the concentrations of each ion present in the final solution.

Gravimetric Analysis

4.83 A chemist added an excess of sodium sulfate to a solution of a soluble barium compound to precipitate all of the barium ion as barium sulfate, $BaSO_4$. How many grams of barium ion are in a 458-mg sample of the barium compound if a solution of the sample gave 513 mg $BaSO_4$ precipitate? What is the mass percentage of barium in the compound?



4.27 If one mole of the following compounds were each placed into separate beakers containing the same amount of water, rank the $Cl^-(aq)$ concentrations from highest to lowest (some may be equivalent): KCl, $AlCl_3$, $PbCl_2$, NaCl, HCl, NH_3, KOH, and HCN.

4.28 Try and answer the following questions without using a calculator.

a A solution is made by mixing 1.0 L of 0.5 *M* NaCl and 0.5 L of 1.0 *M* $CaCl_2$. Which ion is at the highest concentration in the solution?

b Another solution is made by mixing 0.50 L of 1.0 *M* KBr and 0.50 L of 1.0 *M* K_3PO_4. What is the concentration of each ion in the solution?

Practice Problems

Key: These problems are for practice in applying problem-solving skills. They are divided by topic, and some are keyed to exercises (see the ends of the exercises). The problems are arranged in matching pairs; the odd-numbered problem of each pair is listed first, and its answer is given in the back of the book.

Solubility Rules

4.29 Using solubility rules, predict the solubility in water of the following ionic compounds.

a $Al(OH)_3$ b Ca_3N_2
c NH_4Cl d KOH

4.30 Using solubility rules, predict the solubility in water of the following ionic compounds.

a PbS b $AgNO_3$
c Na_2CO_3 d CaI_2

4.31 Using solubility rules, decide whether the following ionic solids are soluble or insoluble in water. If they are soluble, write the chemical equation for dissolving in water and indicate what ions you would expect to be present in solution.

a AgBr b Li_2SO_4
c $Ca_3(PO_4)_2$ d Na_2CO_3

4.32 Using solubility rules, decide whether the following ionic solids are soluble or insoluble in water. If they are soluble, write the chemical equation for dissolving in water and indicate what ions you would expect to be present in solution.

a $(NH_4)_2SO_4$ b $BaCO_3$
c $Pb(NO_3)_2$ d $Ca(OH)_2$

Ionic Equations

4.33 Write net ionic equations for the following molecular equations. HBr is a strong electrolyte.

a $AgNO_3(aq) + NaBr(aq) \longrightarrow AgBr(s) + NaNO_3(aq)$
b $NaOH(aq) + NH_4Br(aq) \longrightarrow NaBr(aq) + NH_3(g) + H_2O(l)$
c $HBr(aq) + KOH(aq) \longrightarrow KBr(aq) + H_2O(l)$
d $K_2S(aq) + 2HBr(aq) \longrightarrow 2KBr(aq) + H_2S(g)$

4.34 Write net ionic equations for the following molecular equations. HBr is a strong electrolyte.

a $HBr(aq) + NH_3(aq) \longrightarrow NH_4Br(aq)$
b $2HCl(aq) + Ba(OH)_2(aq) \longrightarrow 2H_2O(l) + BaCl_2(aq)$
c $Pb(NO_3)_2(aq) + 2NaBr(aq) \longrightarrow PbBr_2(s) + 2NaNO_3(aq)$
d $MgCO_3(s) + H_2SO_4(aq) \longrightarrow MgSO_4(aq) + H_2O(l) + CO_2(g)$

4.35 Lithium carbonate solution reacts with aqueous hydrobromic acid to give a solution of lithium bromide, carbon dioxide gas, and water. Write the molecular equation and the net ionic equation for the reaction.

4.36 Lead(II) nitrate solution and sodium sulfate solution are mixed. Crystals of lead(II) sulfate come out of solution, leaving a solution of sodium nitrate. Write the molecular equation and the net ionic equation for the reaction.

Precipitation

4.37 Write the molecular equation and the net ionic equation for each of the following aqueous reactions. If no reaction occurs, write *NR* after the arrow.

a $FeSO_4 + NaCl \longrightarrow$
b $Na_2CO_3 + MgBr_2 \longrightarrow$
c $MgSO_4 + NaOH \longrightarrow$
d $NiCl_2 + NaBr \longrightarrow$

4.38 Write the molecular equation and the net ionic equation for each of the following aqueous reactions. If no reaction occurs, write *NR* after the arrow.

a $LiCl + Al(NO_3)_3 \longrightarrow$
b $AgNO_3 + NaI \longrightarrow$
c $Ba(NO_3)_2 + K_2SO_4 \longrightarrow$
d $NH_4NO_3 + K_2SO_4 \longrightarrow$

4.39 For each of the following, write molecular and net ionic equations for any precipitation reaction that occurs. If no reaction occurs, indicate this.

a Solutions of barium nitrate and lithium sulfate are mixed.
b Solutions of sodium bromide and calcium nitrate are mixed.